Wavelength Dispersion Amount Estimation Method Compensation Circuit and Reception Device

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Abstract. A wavelength dispersion amount estimation method, a wavelength dispersion compensation circuit, and a receiving device which rapidly estimate and set a wavelength dispersion amount to compensate with high accuracy at the receiving device which compensates waveform distortion at an optical fiber transmission path. The wavelength dispersion compensation circuit includes an analog-digital converter which converts an optical analog waveform received from the optical fiber transmission path to a digital signal, a digital signal processor which compensates waveform distortion of the digital signal output from the analog-digital converter due to wavelength dispersion at the optical fiber transmission path with a dispersion compensation amount estimated with the wavelength dispersion amount estimation method, and a symbol clock extractor which extracts a symbol arrival timing clock of received data contained in the digital signal output from the analog-digital converter and outputs strength of the symbol arrival timing clock as the clock detection value.

Keywords: wavelength, dispersion, amount, wavelength dispersion compensation circuit, reception device.

1. Introduction

In the field of optical communications, a communication system combining a synchronous detection method which dramatically improves frequency usage efficiency and signal processing is attracting attention. Compared to a system constructed with direct detection, it is known to be capable of compensating waveform distortion of transmitting signals due to wavelength dispersion and polarization mode dispersion received owing to optical fiber transmission by receiving as digital signals in addition to improving receiving sensitivity. Therefore, introducing as an optical communication technology of the following generation is considered.

A digital coherent method represented by Non-Patent Literatures 5 and 6 adopts a method to compensate quasi-static wavelength dispersion with a fixed digital filter (e.g., a tap number of 2048 taps with a dispersion of 20000 ps /nm against a signal of 28 Gbaud) and to compensate polarization mode dispersion having variation with an adaptive filtering with the small tap number (e.g., about 10 to 12 taps for polarization mode dispersion of 50 ps) using blind algorithm.

2. Technical Problem

In a transmission system, waveform distortion due to wavelength dispersion applied at a transmission path is compensated with digital signal processing of a receiving terminal at the receiving terminal. Here, there are types of transmission fiber such as single mode fiber, dispersion shift fiber, and non-zero dispersion shift fiber and a wavelength dispersion amount which a signal receives at the transmission path per unit length differs. Further, since an accumulative wavelength dispersion amount increases in proportion to a length of the transmission path fiber through which signal light transmitted, an accumulative dispersion amount varies due to the transmitting distance. In a case that an optical dispersion compensation instrument is inserted to a repeater of the transmitting system, a residual dispersion amount varies owing to the compensation amount thereof. Further, there are cases that a dispersion compensation fiber is used as a transmitting path for a submarine system and the like. Further, since a wavelength dispersion coefficient varies owing to a carrier wavelength of signal light, accumulative dispersion amount is dependent on a wavelength of the signal light. Owing to the above reasons, a coefficient of a dispersion compensation filter should be controlled in accordance with the accumulative wavelength dispersion amount at the receiving terminal. Therefore, a mechanism to estimate the accumulative wavelength dispersion amount which the signal receives is required.

As a conventional art of detecting an optimum wavelength dispersion compensation amount, there is a method of using a characteristic that quality of received signal drops which occurs owing to residual wavelength distortion due to wavelength dispersion. For example, residual wavelength distortion due to wavelength dispersion increases an error rate. Accordingly, there is a method to control a set value for the wavelength dispersion compensation circuit so that the error rate calculated by comparing a known signal pattern and a received pattern becomes small, for example. Further, generally, a synchronous detection signal of a clock extracting-synchronizing circuit becomes small when residual wavelength distortion due to wavelength dispersion exists. There is a method to control the wavelength dispersion compensation amount making use of such characteristics [5]. Further, a method using an opening degree of an eye pattern has been proposed [6].

However, according to these methods, when the accumulative wavelength dispersion amount which the received signal has received and the compensating amount at the dispersion compensation amount circuit largely differs, correlation between a compensating residual dispersion amount and variation of a monitor signal becomes extremely small, so that control of the dispersion compensation amount using the monitor signal becomes impossible. Therefore, a process such as to exhaustively vary and to sweep the dispersion compensation amount is required so that correlation between the residual dispersion amount and the monitor signal can be obtained with the residual dispersion amount. Accordingly, there has been a problem that setting time becomes long.

Meanwhile, a method to estimate a wavelength dispersion amount by inserting a known signal to transmitting signal light and using the known signal part at the receiving terminal from waveform variation of the known signal has been known as a method to rapidly detect the wavelength dispersion amount to compensate[7].

However, although the dispersion estimation method using the known signal is rapid, there is a problem that an error occurs for the estimation amount owing to waveform distortion due to polarization mode dispersion, nonlinear waveform distortion, and the like other than wavelength dispersion.

When an estimated value of wavelength dispersion is set as a compensation amount for the dispersion compensation circuit, waveform distortion due to wavelength dispersion remains even after compensation, so that an error rate increases in cases that an error exists between the actual value which ought to be compensated and the estimated value. Further, proof strength against distortion factors other than wavelength dispersion such as polarization mode dispersion becomes lowered. Accordingly, it is important to reduce the error of the wavelength dispersion compensation amount to operate an optical transmission system stably with high reliability.

As described above, there has been a problem that long time is required until detection for control using a monitor signal and occurrence of an estimation error is required to be considered for a dispersion estimation method using a known signal.

3. Solution to Problem

To achieve the above aim, the wavelength dispersion amount estimation method according includes steps of:

(1) Setting an arbitrary value as a first candidate value of a wavelength dispersion amount,

(2) Extracting plural values close to the first candidate value to set as second candidate values,

(3) Measuring strength of a digital clock extracting signal corresponding to each candidate value,

(4) Extracting an optimum value (the value which becomes the largest) from the tendency of fluctuation of the plural signal strength and to set the value as the next first candidate value,

(5) Performing evaluation while repeating (2) to (4) until a specific condition is satisfied.

Specifically, the wavelength dispersion amount estimation method according is a wavelength dispersion amount estimation method to estimate a dispersion compensation amount for compensating waveform distortion due to wavelength dispersion at an optical fiber transmission path, performing an initial value setting step to set a dispersion compensation amount D(0) which is an initial value (k=0) of a kith dispersion compensation amount D(k) (k is an integer), a clock detecting step to detect and store strength of a symbol arrival timing clock included in received data at the dispersion compensation amount D(k) as a clock detection value S(k), a plus side shifting step to detect and store strength of the symbol arrival timing clock at a dispersion compensation amount D(k)+[Delta]D/M<(k-1) >(M is a real number not less than 1) which is obtained by shifting the dispersion compensation amount D(k) to a plus side by [Delta]D/M<(k-1) >as a clock detection value S(k+), a minus side shifting step to detect and store strength of the symbol arrival timing clock at a dispersion compensation amount D(k)-[Delta]D/M<(k-1) >which is obtained by shifting the dispersion compensation amount D(k) to a minus side by [Delta]D/M<(k-1) >as a clock detection value S(k-), a comparing step to compare the clock detection value S(k), the clock detection value S(k+), and the clock detection value S(k-), and an evaluating step to determine to complete estimation of the dispersion compensation amount as determining the dispersion compensation amount D(k) as an optimum dispersion compensation amount when the clock detection value S(k) is the largest, and to perform the clock detecting step, the plus side shifting step, the minus side shifting step, and the comparing step once again with the dispersion compensation amount of the largest clock detection value set as a k+1th dispersion compensation amount D(k+1) when the clock detection value S(k+) or the clock detection value S(k-) is the largest, as a result of the comparing step.

When a clock detection value of a dispersion compensation amount and a clock detection value of a dispersion compensation amount in the vicinity thereof are compared, it is conceivable that an optimum clock detection value, that is, an optimum dispersion compensation amount exists in the direction of the dispersion compensation amount with a larger clock detection value. Accordingly, the optimum dispersion compensation amount can be obtained by comparing the clock detection values in a comparing step and adjusting the dispersion compensation amount to the direction which enlarges the clock detection value. Further, the wavelength dispersion amount can be rapidly estimated with high accuracy while avoiding overshooting by setting the second candidate value of step (2) in the vicinity of the first candidate value in accordance with the trial number.

Accordingly, provide a wavelength dispersion amount estimation method which rapidly estimates and sets a wavelength dispersion amount to compensate with high accuracy at a receiving device which compensates waveform distortion at an optical fiber transmission path.

The wavelength dispersion amount estimation method according includes an approximate dispersion compensation amount acquiring step in which an approximate value of the dispersion compensation amount is acquired before the initial value setting step and the approximate value of the dispersion compensation amount is set as the dispersion compensation amount D(0) in the initial value setting step.

In the first step, a coarse estimated value is set as the initial value of the dispersion compensation amount estimated with a wavelength dispersion estimation method using a known signal (e.g., see Patent Literature 4) or the like. Estimation of an optimum dispersion compensation amount can be performed in a short time by performing a step to perform fine adjustment after the first step.

In the wavelength dispersion amount estimation method according, at least one of the clock detecting step, the plus side shifting step, and the minus side shifting step is repeated several times at different time to perform averaging.[0031] Stabilization can be achieved even when local variation exists by averaging the clock detection values through time.

In the wavelength dispersion amount estimation method according, a minute amount [delta]D which is smaller than the predetermined amount [Delta]D for shifting the dispersion compensation amount in the plus side shifting step and the minus side shifting step is set, a clock detection value S(k+-0) at the dispersion compensation amount D(k), which is a center value and clock detection values S(k+-no) at dispersion compensation amounts D(k)+-n[delta]D(n is a natural number) around the dispersion compensation amount D(k) are detected in the clock detecting step, a clock detection value S(k+-0+) at the dispersion compensation amount D(k)+[Delta]D/M<(k-1) >and clock detection values S(k+-n[delta]+) at dispersion compensation amounts D(k)+[Delta]D/M<(k-1)>+-n[delta]D(n is a natural number) around the dispersion compensation amount D(k)+[Delta]D, which is the center value are detected in the plus side shifting step, and a clock detection value S(k+-0-) at the dispersion compensation amount D(k)-[Delta]D/M<(k-1) >and clock detection values S(k+-n[delta]-) at dispersion compensation amounts D(k)-[Delta]D/M<(k-1)>+-n[delta]D(n is a natural number) around the dispersion compensation amount D(k)-[Delta]D, which is the center value are detected in the minus side shifting step

Stabilization can be achieved even when local variation exists by averaging the clock detection values around the dispersion compensation amount.

In the wavelength dispersion amount estimation method according to the present invention, the clock detection value S(k) is obtained by averaging the clock detection value S(k+-0) and the clock detection values S(k+-n[delta]), the clock detection value S(k+) is obtained by averaging the clock detection value S(k+-0+) and the clock detection values S(k+-n[delta]+), and the clock detection value S(k-) is obtained by averaging the clock detection value S(k+-0-) and the clock detection values S(k+-n[delta]-).

Stabilization can be achieved even when local variation exists by averaging the clock detection values around the dispersion compensation amount.

In the wavelength dispersion amount estimation method according to the present invention, estimation of the dispersion compensation amount is completed while the dispersion compensation amount D(k) is determined as an optimum dispersion compensation amount when a difference between the clock detection value S(k) and the clock detection value S(k+) and a difference between the clock detection value S(k) and the clock detection value S(k-) are smaller than a predetermined threshold value in the evaluating step.

Estimation operation can be stabilized by avoiding to perform estimation in a state that difference among the clock detection values are small and the direction of which the optimum value exists is uncertain.

The wavelength dispersion compensation circuit according includes an analog-digital convertor which converts optical analog waveform received from the optical fiber transmission path into a digital signal, a digital signal processor which compensates waveform distortion due to wavelength dispersion at the optical fiber transmission path of the digital signal output from the analog-digital convertor with the dispersion compensation amount estimated with the wavelength dispersion amount estimation method, and a symbol clock extractor which extracts a symbol arrival timing clock of received data included in the digital signal output from the analog-digital convertor and outputs strength of the symbol arrival timing clock as the clock detection value.

The wavelength dispersion compensation circuit according adopts the wavelength dispersion estimation method. Accordingly, the present invention can provide a wavelength dispersion compensation circuit which rapidly estimates and sets a wavelength dispersion amount to compensate with high accuracy at a receiving device which compensates waveform distortion at an optical fiber transmission path.

The receiving device according includes the wavelength dispersion compensation circuit. Accordingly, the present invention can provide a receiving device which rapidly estimates and sets a wavelength dispersion amount to compensate with high accuracy at a receiving device which compensates waveform distortion at an optical fiber transmission path.

4. Explanatory view of a receiving device according

Fig. 1 is an explanatory view of a receiving device according. The receiving device includes a wavelength dispersion compensation circuit. The wavelength dispersion compensation circuit includes an analog-digital converter which converts an optical analog waveform received from an optical fiber transmission path to a digital signal, a digital signal processor which compensates waveform distortion of the digital signal output from the analog-digital converter due to wavelength dispersion of the optical fiber transmission path with a dispersion compensation amount estimated with a wavelength dispersion amount estimation method described in the following, and a symbol clock extractor which extracts a symbol arrival timing clock of received data contained in the digital signal output from the analog-digital converter and outputs strength of the symbol arrival timing clock as the clock detection value.

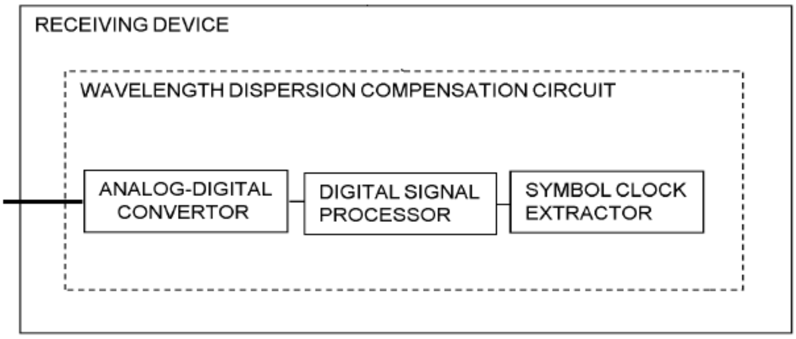

Fig. 1 is an explanatory view of a receiving device according

First, as a coarse adjustment process, a coarse estimated value estimated by a wavelength dispersion estimation method using a known signal or the like is set to a dispersion compensation circuit as an initial value. At this time, most part of the wavelength dispersion is compensated and a waveform receiving waveform distortion due to residual dispersion occurring for an estimation error and the like is output from the dispersion compensation circuit.

Subsequently, a fine adjustment process starts. FIGS. 2(a) to 1(c) and FIG. 3are explanatory views of the fine adjustment process according. D (k) denotes a dispersion compensation amount set to the digital signal processor. First, as the first step, a dispersion compensation amount D (0) for the initial value k=0 is set and a detection signal value of clock synchronization is measured and stored on a memory. This value is denoted as a clock detection value S (0). Next, following processes are performed as the first step as illustrated in FIG. 2(a).

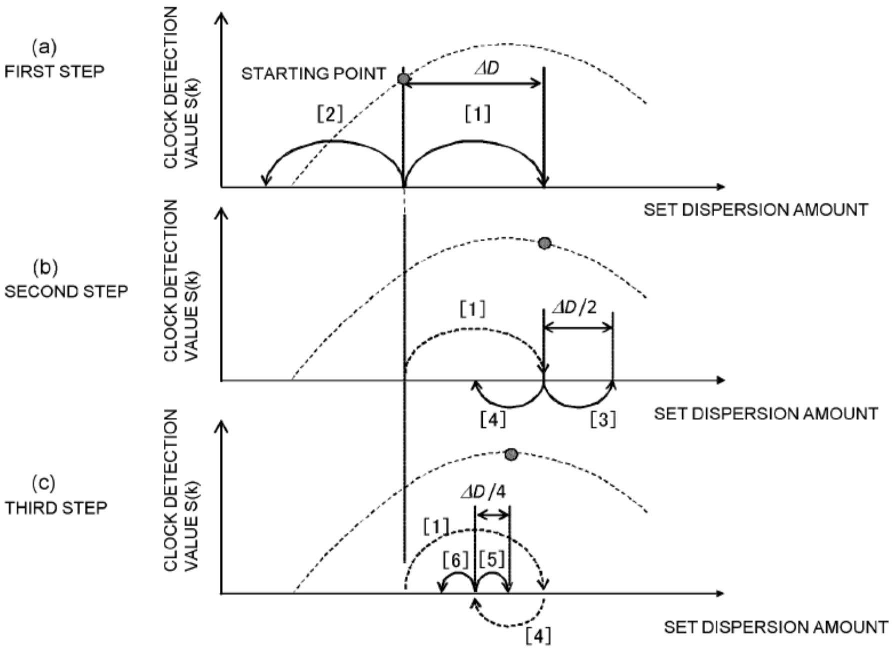

Fig. 2 explanatory view of a wavelength dispersion amount estimation method according

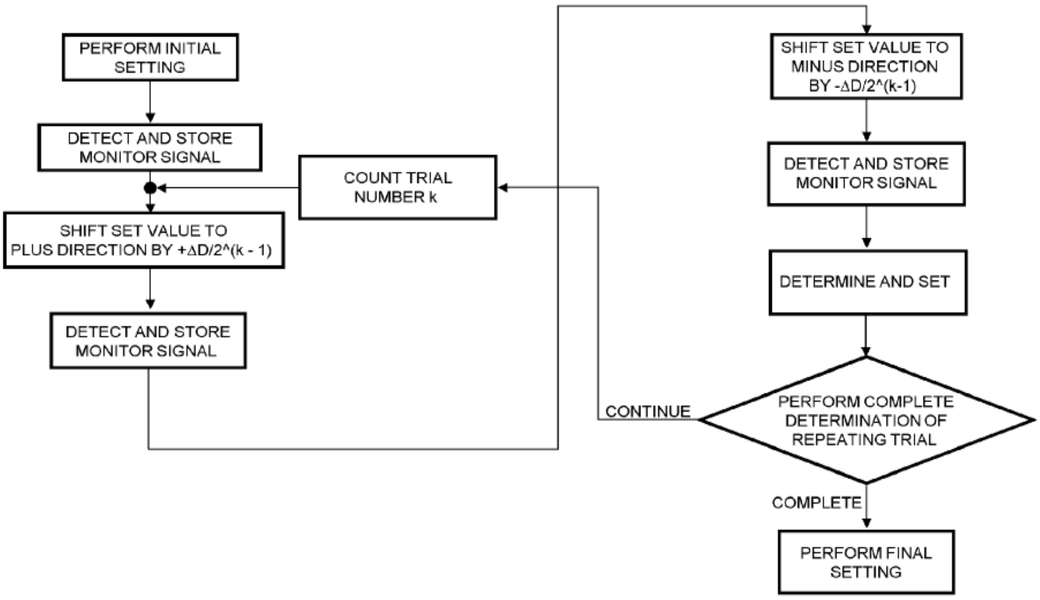

Fig. 3 flow diagram illustrating the wavelength dispersion amount estimation method according

[1] The dispersion compensation amount is shifted to the plus direction by a constant shift value [Delta] D from the dispersion compensation amount D (0) (dispersion compensation amount D (0) + [Delta]). Then, a clock detection value S (0+) of clock synchronization is measured and stored.

[2] Similarly, the dispersion compensation amount is shifted to the minus direction by the constant shift value [Delta] D from the dispersion compensation amount D (0) (dispersion compensation amount D (0)-[Delta]). A clock detection value S (0-) of clock synchronization at that time is measured and stored.

The constant shift value [Delta] D is set to the order of a maximum value of a gap amount of the initial value from an expected value. Here, the initial value depends on a coarse estimation algorithm (e.g., an algorithm of Patent Literature 4) to be used. For example, [Delta] D is set in a range of 300 to 1000 psec/nm with an assumption that an error is in a range of 1.5% to 5% of a dispersion amount 20000 psec/nm exemplified in Patent Literature 4 as a compensation range.

It is conceivable that an optimum value exists in the sign direction where the clock detection value is large. Therefore, S (0), S (0+), and S (0-) are compared. When the clock detection value satisfies S (0+)>S (0-), a next dispersion compensation amount D(1) is set to D(0)+[Delta]D. Conversely, when the clock detection value satisfies S (0+) < S (0-) , the next dispersion compensation amount D(1) is set to D(0)-[Delta]D. When both of S(0+) and S(0-) are smaller than S(0), that is, when S(0)>S(0+) and S(0)>S(0-) are satisfied, the dispersion compensation amount D(1) is set to D(0).

Here, assuming a case of S (0+)>S (0-) , following processes will be described as the dispersion compensation amount D(1) is set to D(0)+[Delta]D.

As a second step illustrated in FIG. 1(b), the dispersion compensation amount is shifted to the plus direction and the minus direction by a shift amount [Delta] D/2 from the dispersion compensation amount D (1) =D (0) + [Delta] D, which is the center value ([3] [4]). Clock detection values S (1+), S (1-) when the dispersion compensation amount is set to D(1)+[Delta]D/2, D(1)-[Delta]D/2 respectively are detected and stored on the memory. Then, comparing the both, a compensation dispersion amount D(2) is set to D(1)+[Delta]D/2 when S(1+)>S(1-) is satisfied and D(1)-[Delta]D/2 when S(1+)<S(1-) is satisfied. Further, a case that both S (1+) and S (1-) are smaller than S(1), that is, S(1)>S(1+) and S(1)>S(1-) is conceivable as well. In this case, D (2) is set to D (1). Here, following descriptions will be performed with the compensation dispersion amount D(2) set to D(1)-[Delta]D/2 assuming a case satisfying S(1+)<S(1-).

As a third step, the dispersion compensation amount is shifted to the plus direction and the minus direction by a shift amount [Delta]D/4 from the compensation dispersion amount D(2), which is the center value ([5] [6]). Clock synchronization detection signals S (2+), S (2-) when the dispersion compensation amount is shifted to the plus direction and the minus direction respectively are detected and stored on the memory. Then, the both are compared and shifting is performed to a larger sign direction. An optimum compensation dispersion amount can be asymptotically acquired by repeating the similar processes thereafter. Here, the shift amount of a compensation dispersion amount D (k) in the kth step is set to [Delta] D/ (2< (k-1)>)) to be halved for each proceeding process.

In this manner, the process is repeated with the shift amount halved as [Delta] D/2, [Delta] D/4, [Delta] D/8 . . . The number of repeating time is required to be set so that repeating is performed until the shift amount becomes smaller than the final target error range. For example, when [Delta] D is set to 1024 psec/nm and the target error is set to 50 psec/nm, the shift amount varies as 1024, 512, 256, 126, 64, 32, and 16 (psec/nm) for each process. Accordingly, the process is required to be repeated for about six or seven times until the shift amount becomes smaller than the target error. The process may be repeated until the shift amount becomes further smaller if time allows.

Here, since the detection signal primarily includes an error, there is an opportunity to set S (k) again and redo measurement when difference among S (k+), S (k-), and S (k) are smaller than the set threshold value. Owing to the above, risk of inducing unstable operation by shifting on a basis of uncertain information can be reduced in a situation where the difference is small and the direction in which the optimum value exists is uncertain to be whether plus or minus. Here, the shift amount for the compensation dispersion amount D (k) is halved for each step, that is, described as [Delta] D / (2< (k-1)>) in the above example. However, the shift amount may be set to [Delta] D/ (M< (k-1)>) (M is a real number not less than 1).

In the above method, the process determines the set value of the dispersion compensation amount with one measurement value of the clock detection signal for each set value. Accordingly, when an error of S (k) at each measurement is large, there is a possibility that the sequence of optimization becomes an unstable operation. As a method for stabilization, by measuring plural times at different time for each set value and determining which direction of plus or minus sign to shift by comparing the average value thereof, stabilization of the operation is expected.

5. Conclusion

The present invention can provide a wavelength dispersion amount estimation method, a wavelength dispersion compensation circuit, and a receiving device which rapidly and efficiently estimate and set a wavelength dispersion amount to compensate at a receiving device which compensates waveform distortion at an optical fiber transmission path.

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